ON OBSERVATIONS OF SOLAR AND SKY RADIATIONS AND THEIR IMPORTANCE TO CLIMATOLOGY AND BIOLOGY AND ALSO TO GEOPHYSICS AND ASTRONOMY.[1]

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SYNOPSIS.—Treated statically, solar and sky radiation measurements pertain to meteorology and climatology; while investigations into the variations of these two components and the causes thereof pertain to geophysics, astrophysics, and astronomy.

It is partly due to this division of interest in the problem, partly to lack of suitable measuring apparatus, and partly to lack of appreciation of the many practical applications of the results, that solar and sky radiation measurements have heretofore received so little attention.

From 1908 to 1910, inclusive, measurements were made at Davos, Switzerland, of the heat, the illumination, the chemical, and the ultra-violet intensity of solar radiation, and the means have been found to represent with sufficient exactness the radiation values for every hour of the day. Radiation values have also been coordinated with durations of sunshine and conditions of cloudiness.

The solar constant is one of the most important constants in nature, since upon it depends all organic life. For different climatic effects radiation, including the outgoing as well as the incoming, is among the most decisive elements. In the Alps spring sunshine is relatively rich in heat rays, autumn sunshine in ultra-violet rays. With average elevation of the sun in a cloudless sky the red solar light falling upon a horizontal surface is 14 times stronger than skylight, the visible rays 11 times stronger, the chemical rays 4 times stronger, and the ultra-violet only half as strong. It follows that photographic measurements of sunlight give no adequate indication of the solar climate of a place.

Measurements of the relative brightness of the sun and sky give a means of determining the atmospheric transmissibility. Observations of purely optical phenomena and especially optical disturbances have been found useful in the study of the atmosphere. The expression of the separate components of polarized light in absolute measures has afforded the possibility of explaining the variations of sky brightness, polarization, and color, dependent upon solar altitude and atmospheric transmissibility. It has been found that all the optical phenomena are closely related.—*H. H. K.*

INTRODUCTION.

The problem of solar and sky radiations can be considered from two entirely different view points—first, we may be content to record in a purely statistical way what amounts of radiation reach the earth's surface at the place of observation, and to determine the totals and distribution for the time of day and season of the year; then, we may inquire into the direct connection between solar and sky radiation and seek to investigate the variations which the two components show, and the origin and causes of the same.

The first part of the problem pertains to meteorology, especially "geographic meteorology", or climatology, and is useful in this science and through it in biology as a whole. The second part of the problem lies in the realm of geophysics, astrophysics, and astronomy.

Although almost all branches of natural science, including medicine, are concerned in the problem, and every one is individually and seriously interested—as is immediately evident and demonstrated right before our eyes by the restrictions relative to illumination and heating necessitated by the stress of war—still its solution is singularly delayed, and even to-day is not taken in hand as systematically as might be wished. Meteorology had to refuse to undertake the problem, although it concerns its chief and primal element, since, until lately, sufficiently simple, inexpensive and readily manipulated apparatus was lacking, and only a few observatories with personnel fully trained in scientific matters attempted the task; geophysics, astrophysics, and astronomy, occupied with the solution of more immediate and specifically interesting investigations, awaited the solution of the problem apparently belonging to the sister sciences; and until recently its importance appears to have been underestimated, and even at present, its value is not fully appreciated, despite the astonishing results in particular fields of solar investigation, Nevertheless, the results already realized are truly abundant enough to be referred to with pride; the way to decided results is paved; interest manifests itself in many directions—on the part of physiology and hygiene in an urgent call for the delivery of climatic radiation constants—and nowhere will such interest fail to appear when there is comprehension of the significance of the problem; in general, proper organization alone is necessary.

METHODS OF MEASUREMENT.

When, more than 14 years ago, I selected the high mountains as a place of residence I was soon convinced that radiation there presented one of the most important climatic factors; that up to that time its amount was more estimated than measured; and that the measurements based on summer expeditions by celebrated representatives of physics could give no sufficient conception of it; that the statements of literature, especially medical literature, were rather fragmentary and in part not free from error. Again, I was convinced that if the prerequisite conditions for accurate and adaptable continuous observations were compiled with both theoretically and instrumentally, the method of measurement, in order to be sufficient for the demands of practice, must begin with the well-known chief effects of radiation, namely, calorific, luminous, chemical, and bactericidal.

The wondrously exact spectro-analytic methods could not solve the problem since they were applied only to the most favorable, selected conditions; and from values relating to spectrum line width alone they did not permit simple conclusions as to the intensity of the entire solar spectrum nor of the larger portion of the spectrum as required in practice; then the numerous and widely employed photographic methods for the measurement of the illumination of the horizontal surface were not sufficient since, for the most part, they were entirely too inexact, and furthermore they took into consideration short-wave radiations exclusively, and these in rather inexactly defined portions of the spectrum.

The methods chosen for the accomplishment of the measurement which sufficed for the end to be attained were until 1907 employed at only a few places, never in connection with one another, and they had to be partially modified with application to conditions on high mountains. For the measurement of the heat intensity of the sunlight there was immediately available the Ångström compensation pyrheliometer, an instrument pronounced standard at the International Meteorological Directors' Conference at Innsbruck, soon supplemented by the rather readily manipulated and permanently highly trustworthy Michelson actinometer. For brightness measurements L. Weber's method, not connected with keenness of vision and thereby best meeting practical requirements, furnished a gratifyingly certain basis, and a broad one—since in addition to the equivalent value for the brightness it gives the intensity in red and green. Applied to regular observations only by the inventor at Breslau, later at Kiel for some decades, it fur-

[1] Presented at the one hundredth anniversary of the "Schweizerische Naturforschende Gesellschaft" at Lugano.

nished until then the only exact values with which hygienists might reckon and on which they could base rules for the illumination of interior spaces. For the determination of chemically active rays there served a photographic method, perfected by Konig and Weber and applied at a forest culture school to continuous observations—difficult, it is true—but one meeting strictly scientific demands. The ultra-violet radiation, in which the chief healing action was sought by medical science, was qualitatively investigated by means of the recording spectrograph made according to special instructions by Zeiss, and used chiefly for the determination of the extent of the ultra-violet spectrum and the change in its extent with the seasons of the year and the hours of the day, and quantitatively by means of the most exact instrument of this class, Elster and Geitel's zinc spherical photometer—which meanwhile has been far surpassed by the selfsame investigators with the use of cadmium and potassium cells.

After continuous observations with the use of this apparatus were carried through three years (1908–1910) and the results were combined in tables, which, in addition to giving—as customary—the air masses traversed according to elevation of the sun and hour of the day and the "normal values," showed the changes of these normal values under the influence of different degrees of cloudiness, brightness, and elevation of the sun, then the physician, for whom the work was first contemplated, was placed in the position to read in exact figures the radiation values for every hour of the day; also equally favored were the meteorologist, the climatologist, and the biologist. Haphazard observations carried on in later years have shown that normal values were derived with sufficient exactness by the 3-year observation series. The value of this working method lies, among other things, in the fact that measurements require only a single series of observations, which, to be sure, must be sufficiently long for an exact comprehension of the normal values, and in the fact that the deduction of definite values is referred once for all to the observation of duration of sunshine and conditions of cloudiness, which nowadays is everywhere furnished by meteorological services.

Naturally, effort is to be made to acquire recording instruments. There is a common misconception as to the difficulty of accurately manufacturing and giving practical attention to such instruments used for the simpler elements of air pressure, humidity, and temperature; for radiation measurements these difficulties are far greater, since isolation from immediate surroundings is to be obtained only with very costly and extensive auxiliary devices.

GREAT DIFFERENCES IN RADIATION FROM TIME TO TIME AND PLACE TO PLACE.

In the adaptation to practical use the greatest consideration should be given to the contents of the book, Essay on the Light and Air of High Mountains (Viewegs, 1911), which, in addition to radiation values, treats of atmospheric electricity, and radioactivity; besides, consideration should be given to comparison of results of measurements with respect to characteristics at other places in the same radiation region and also at those in other regions. Such comparison may show that the differences in absolute amount of radiation and in distribution through the day and the year, from place to place, are far greater and therefore more characteristic than those of the other meteorological elements; whence it might be concluded that for different climatic effects radiation is among the most decisive elements. In this there is to be considered not only the difference in the amount of insolation, but also that in outward radiation, since not only at night, but also by day there occurs in high mountains and prevalently everywhere in the polar and temperate regions a radiation from the earth to the sky except in the immediate vicinity of the sun.

A few numerical examples may be interesting. At noon in midwinter Davos has 6 times the brightness of Kiel; in midsummer, 1.8; and for the yearly mean, 2.5 times the amount of the latter. The high mountain has thus a very much brighter illumination than the plain and very much more favorable distribution of this brightness through the year, since the winter brightness exceeds that of the plain very much more than does the summer brightness. The amplitude of the monthly means amounts to 3.0 at Davos, 7.9 at Kiel; the amplitude of the absolute maxima and minima amounts to 32.3 at the former, 219.0 at the latter. At Davos with snow covering in winter the mean illumination of the vertical surface at angles of 0°, 90°, 135°, and 180° to the sun direction (*Vorderlicht*), which thus includes the reflection of the ground, equals the illumination of the horizontal surface (*Oberlicht*), while in summer it totals barely three-fourths of the same. So far as comparisons are at present possible the effect of snow reflections exceeds those of the beach and the sea surface. In winter the sun sheds on Davos three times the amount of heat that Potsdam receives; in summer the differences are moderate. Also in this connection there is evident the especially favorable distribution of the amounts of radiation through the year in the high mountains. Of all places from which data are available Davos has by far the greatest heat total, although as a result of valley location there is an average daily loss of three hours' sunshine; only the more southerly situated Washington with its entirely unobstructed horizon reports a slightly higher value.

The solar radiation is by no means always similarly composed; the low sun is much richer in long-waved radiations (much redder) than the high sun, as every one knows from experience. Also with the same elevation of the sun there exists a pronounced yearly march. The spring sunlight is—at least on the Alpine heights—much richer in heat rays, that of autumn much richer in the ultra-violet ones. The difference between sunlight and shadow light increases in marked degree with elevation of the sun and still more so with the color of the light, since the sky, as appearance teaches, is much richer in short-wave (blue) light than the sun with its long-wave rays (infra-red, red, and yellow). With middle sun elevations and cloudless sky the red light of the sun falling on the horizontal surface is found to be 14 times stronger than that from the sky, while its brightness is only 11 times stronger, its chemical rays only 4.4 times, its pure ultra-violet (bactericidal) rays even less strong than those of the sky (only about half so powerful).

From this it follows that a photographic method, were it even, as the Weber-Konig, exact to about 2½ per cent and not, as the widely used Weisner, to only 20 per cent, can never sufficiently characterize the light climate of a place. By a 9-month parallel series for the illumination of the horizontal surface the author has demonstrated that the light totals of the direct rays, with high elevation of the sun, are measured 2.0 times as great photographically as photometrically, those of diffuse sky light at low elevation of the sun about 4.5, at high elevation, 7; those of the total light at low sun elevation 1.75, at high elevation, 2.75 times as great, provided the minima are taken equal; and the ratio of sunlight to shadow light will be found 3.4 times higher photographically than photometrically in the yearly mean, varying between 5.0 in winter and 2.0 in summer. It is seen that there is a question of a difference of hundreds of per cent. Those who are able to appreciate such figures will read attentively because of these few examples, and will immediately understand the importance of comparative measurements at different places.

PHYSIOLOGICAL IMPORTANCE.

"Suggestions for the Systematic Study of Light Climate and Air Climate of Places of Interest to the German Physician," written at the suggestion of Prof. Dietrich, of the Ministry of the Interior, the intellectual leader of the Central Office of Balneology, found full recognition, and Prof. Hellmann, who followed similar plans, supplemented the work in ample manner. If complete success has not been attained it is due to the sorrowful events of the day.

However, some stations parallel to Davos are established and some of these have been in operation for a long time, as for example, Potsdam and Kolberg, whose data should soon be given publicity. At Oberhof preparation was made for continuous observations; in the North Sea islands work was carried on by doctors from Kiel and physiologists from Berlin. At Essen and thence out into the Teutobergerwald stations are located, likewise on the Feldberg in the Taunus; St. Blasien has begun observations. In Allgau careful solar intensity observations have been made for several years. The aeronautical observatory at Lindenberg has taken up the problem with characteristic energy; P. Schreiber reported a few values from the Saxon Weather Service (Wahnsdorf). Then too there must be permanent and temporary stations that have not come to the attention of the author directly or indirectly. Interest is aroused outside of Germany; in Switzerland, crossed by the Alpine crest dividing weather and climate and therefore specially suited to comparative measurements, the first steps toward the inauguration of such have been taken; in the Baltic Provinces of Russia such measurements were nearing achievement shortly before the war; conditions were similar in Holland; while in Austria, in many ways leading in meteorological science, there is unfortunately still the belief that success may be had with the Weisner method. If last mention is made of the pioneer stations in heat radiation measurements, Upsala, Stockholm, Moscow, and Warsaw and of the standard solar intensity measurements in the United States, it is because they have hitherto been occupied almost exclusively with the total energy, and not with that of the separate portions of the spectrum, or have not turned knowledge of such to account climatologically when it has been obtained in solar investigation.

The requirement question was briefly touched upon heretofore. Just a short time ago one of the foremost hygienists of Germany complained to me that he must consider the values of brightness given by Weber for Kiel as by no means representing mean conditions in Germany. How shall the physiologist or the biologist arrive at certain results in his research work when he does not know the intensity and spectral composition of the sunlight and daylight at his disposal, and may err by hundreds of per cent in its estimation? In laboratory experiments he calculates with the accuracy of a few per cent, while on the other hand the meteorological factors which combine in nature are practically missing. The same holds for therapeutic light baths. Investigation on one hand with artificial light, with attendant influences unavoidably more or less harmful, or at least by no means curative, and on the other with sun and air baths must supplement each other; and there is certainly still difficult work to perform before no doubt shall prevail as to the utility of the different factors, and opportunity shall be given to use fully this natural and truly not ineffective source of healing. In order to get a striking example of the question of requirement let medical literature on the effect of light on the blood be read; even with the most serious physicians there enters not rarely at the conclusion of all reflections the question of a still entirely unknown, mysterious content of solar radiation, which idea persists, and a positive solution of this exceedingly important question can hardly be expected until the physician is placed in a position to investigate the effects of different spectral portions on the blood as compared with unchanged natural conditions.

If the desired end is to be attained, one thing is necessary; perfected organization, which should give attention to the following: Accurately adjusted, uniform apparatus and a program of observation and elaboration; synchronous observations, since optical disturbances are not rare; the employment of absolute and fixed measures, adaptable to the ordinary artificial sources of light; an industrious observing personnel, well educated in physics.

One of the established meteorological or geophysical observatories will, in view of the important and urgent nature of the problem, be found disposed to carry it into execution, and the opportunity will arise since international arrangements among all civilized countries will again be possible.

BEARING ON GEOPHYSICS AND ASTRONOMY.

Let us now turn to the advances and interests of geophysics and astronomy. These are great and, thanks to Abbot, are celebrating a triumph in the United States. May the demands which such extraordinary popularity makes of the scientific investigator not interfere with prosecution of his work!

The procedure in the determination of the solar constant and of the extraterrestrial solar spectrum, on which many other investigations hinge, which was established by Langley and largely and accurately developed by Abbot and his coworkers, Fowle and Aldrich, with the aid of munificent endowments and through indefatigable zeal, extraordinary intellectual grasp, experimental ingenuity, and technical skill, consists essentially in the following attainment. It is possible within only 11 minutes to register photographically the energy curve of the entire solar spectum from extreme infra-red to extreme ultra-violet so exactly that, for example, even the delicate nickel line lying between the two D lines of sodium comes to view, and simultaneous determinations of the heat intensity of solar radiation can be proceeded with through the employment of a pyrheliometer excelling the Ångström instrument and protected with extreme care from the radiating influences of the surroundings.

Through the combination of these two methods of measurement there is obtained both the distribution of energy and the energy of any spectrum portion in absolute terms. If several such curves at different sun elevations and with unchanged atmospheric conditions are considered, then the total energy of the extraterrestrial spectrum and its distribution may be inferred by extrapolation. Those who wish to be informed in detail on the method of measurement and generally on the whole extensive problem of sun and sky radiations may refer to volume 63 of "Die Wissenschaften" (Vieweg). In it will be found the essential facts as to the composition of the atmosphere up its highest elevations (estimated at some 500 km.) and the laws according to which it acts through dispersion and absorption on the solar radiation traversing it, and also the results to which these processes lead; namely, polarization of light and color of the sky; also there will be found the optical influences of water vapor and cosmic and telluric dust. The statements made in that paper must be considered as preliminary to the full understanding of the following geophysical discussions.

THE SOLAR CONSTANT.

Of the results obtained, chiefly on Mount Wilson in California (1730 m.) and to be credited principally to Abbot, a few may be given here. These have been checked and supplemented by extremely careful and varied parallel observations at numerous places on the earth, often by German hand and with measurement methods and apparatus originating in the German mind.

The solar constant, that is, the intensity of solar radiation on its entrance into the earth's atmosphere, or the energy supplied at that point to a square centimeter in the path of the radiation in one minute, amounts to 1.925 gr. cal./min. cm.^{2} This is a mean value from hundreds of measurements; in reality the values vary a few per cent with dependence on solar activity; an increase in the value of the solar constant accompanying an increase in sunspots. In rough approximation an increase in sunspot number of about 100 corresponds to an increase of 0.07 calorie in the solar constant. According to the latest investigations solar radiation appears to stand in more certain relation to change in distribution of brilliancy over the entire disk of the sun than to sunspot number. The value of the solar constant decreases with decreasing contrast in brilliancy from the sun's center to limb. According to this the radiation oscillations resulting from a rupture of separate places in the sun's envelope are slighter than those from a change affecting the entire solar sphere. Periodic oscillations within the duration of a day are believed to have been observed occasionally, but they are not to be considered as established; such changes of hours duration, which are assumed in analogy to the periodic brilliancy of fixed stars of the sun's age, in so far as they exist, must lie below 1 per cent.

The temperature of the photosphere is calculated from the solar constant and from the position of the maximum of energy in the solar spectrum according to Stefan's and Wien's laws of radiation, in apparently good agreement with one another, at about 6,000° C., assuming that the sun radiates as a dark body. From the deviations of the energy curve of the extraterrestrial solar spectrum as compared with that of the dark body the temperature must be estimated higher, between 6,000° and 7,000° C. In the paper mentioned there are to be found the most important facts relative to the curves of the extraterrestrial and of the terrestrial solar spectrum, their oscillations, the causes of premature diminution on the short-wave and long-wave ends, the origin of absorption bands, and the conclusions to which the same have led. However, this can not be entered upon at this place.

As is immediately obvious, the solar constant is one of the most important constants in nature, since on it depends all organic life. Exact knowledge concerning it is therefore of the greatest importance, and for this reason there has been no lack of very sharp criticism of the Langley-Abbot method. So far as these relate to change of atmospheric transmission during the time of observation, to too feeble resolvent power of the lens, to defect in apparatus, and to methods of calculation, one should not attach to them too much value. But on the other hand lies the fact that as to radiation that does not reach the ground nothing can be ascertained by process of extrapolation. Usually the errors entering in this way are estimated at only a few per cent, and the value of 5.85 at the limit of the photosphere as derived by Bigelow by nonadiabatic thermo-dynamics, allowing for gravitation, and of 3.98 at the limit of the earth's atmosphere must stand, on the whole, disproven by Very's and Abbot's replies. Bigelow's four fundamental formulas advanced in quite recent time and the conclusions which he draws from them relative to pyrheliometry require further proof.

SKY RADIATION.

What valuable application a better guaranteed value of the solar constant can find in geophysics has been demonstrated by Abbot and Emden. The former, having recourse to supplementary heat radiation measurements of the cloudless sky, of the earth, and of the clouds (distinguished as higher and lower) derived 0.37 as the energy albedo of the earth as a planet. From this value, the ground temperature, and the solar constant Emden was able to calculate the decrease in radiation by the atmosphere with height, and the retention of heat which the different zones of the earth experience in the different seasons through the sheltering mantle of the atmosphere. According to this, the radiation from the sky exceeds in winter everywhere except at the equator, and in middle Europe in January the atmosphere radiates two or three times more heat to the earth than is radiated by the sun, since, as a result of the general circulation, at this season air masses laden with heat and capable of radiation are carried from equatorial into higher latitudes. In these calculations Emden treats the short-wave solar radiations and the long-wave atmospheric radiations separately and assumes both kinds as gray with different absorption coefficients. His values agree very well with values of outward radiation ascertained by measurement. The wide employment of the last class of measurements is to be encouraged, and here I may direct attention to the small instrument, "tulipan," devised by Ångström. It is based on the principle of compensation for the cooling of a black surface radiating to the sky by the overdistillation of ether vapor. Although liable to error, the instrument is, according to may experience, still adaptable and furnishes for the outward radiation amount an integral value for the entire night, which serves as a valuable supplement in judging of conditions during the night. It may be noted here that Fowle by laboratory experiments on a grand scale, with tubes 128 and 246 meters long, has arrived at a spectrographic method for determining the water vapor content of the entire atmosphere up to its highest limit, which appears to leave nothing to be desired as to precision, and which has stood successfully many tests in connection with records from balloons

With Abbot's above-mentioned albedo value for the cloudless sky there stands in correct relationship the parallel value, which the author has ascertained by extensive measurement as to the light economy of the atmosphere.

OPTICAL PHENOMENA.

The purely optical phenomena have proven especially productive of results in the investigation of the atmosphere, and thereby in geophysics. First from the consideration of auroral and meteoric phenomena connectedly they have essentially confirmed the computations as to the composition of the atmosphere up to an elevation of 500 km. which were begun by Humphreys and Hann and systematically developed by A. Wegener; in which connection optical disturbance, in addition to twilight phenomena, have contributed abundantly. So far as the relatively brief time of the observations permits judgment these last again make it very probable that a continuous relation exists between them and solar activity, of which one must make a threefold differentiation—(1) an indirect relation, since at the time of solar activity volcanic activity on the earth usually increases, and this changes the permeability of the atmosphere in well understood range of time and space; (2) a direct relation, parallel to the 11⅓-year solar period; (3) an enduring relation, corresponding to each separate evolution of solar energy, originating suddenly, continuing relatively briefly, and by no means affecting all places on the earth equally, since the incidence of corpuscular radiation from the sun will hardly take place in like manner and with equal force at all places on the day side of the earth, much less then on the night side, and the electrically laden particles will follow the earth's field of force.

With the superposition of these classes of disturbances explanation becomes difficult; purely meteorological influences of the lowest atmospheric strata can often prevent the possibility of observation, and, what is of more consequence, can give opportunity for misinterpretation, for example, through the occurrence of entirely uniform, thin haze, and through the influence of the seasons, which is an unexpectedly great one, judging from the author's extensive investigations at an elevation of 1,600 meters. The preliminary condition for correct interpretation is a very accurate study of the unclouded sky, and only places in specially favorable location will permit the prosecution of such study with sufficient accuracy, probably only those situated more than 1,000 meters above sea level, on extended plateau, and at a distance from the sea.

From vocation the author had the good fortune to be located at such a place, and he has attempted—he will acknowledge in ignorance of the extent of the problem, otherwise he had not ventured—to enter upon such a study of normal values, and to give through it a basis for trustworthy comparison with the phenomena of disturbance periods. Furthermore, he was fortunate in that tests were once possible at the time of conspicuous volcanic phenomena after the eruption of Katmai (1912–1914), and afterwards at the time of briskly reviving solar activity; so that the fundamentally different optical disturbance phenomena, coming at one time from within and at the other from without, could be evaluated quantitatively and qualitatively. There have been established normal values of absolute brightness, of amount of polarization, and of the position of the polarization plane for each point of the sky at all elevations of the sun and at all seasons, and indeed, except in equivalent values of brightness, also (to greater or less extent) in numerous spectral colors as far as into the pure ultra-violet. At the same time the albedo of the ground with different coverings and the influence of the natural horizon had to be ascertained. Control measurements of the illumination of the horizontal surface by sunlight and skylight have demonstrated the correctness of the results. Calculation in regard to the light economy of the atmosphere, which were made possible by determinations of the intensity of solar radiation carried on at the same time, have led to an intelligent course of reasoning. The expression of the separate components of polarized light in absolute measure afforded the possibility of a comprehensive and coherent explanation of all the variations of brightness, polarization, and color arising from dependence on elevation of the sun and atmospheric transmissibility, and the opportunity of investigation as to the extent to which the dispersion of light in the high mountains follows the laws contained in the prevailing theories. The results are collected in the papers of the Prussian Meteorological Institute, Vol. V, No. 295 (1917), and Vol. VI, No. 303 (1919).

It has been found that no one of the numerous optical phenomena is without close relation to the others; in agreement all have led to the same explanation as to the location and class of the disturbances, and demonstrate that by such observations there is obtained accurate information as to the character and extent of optical disturbances; some examples might be advanced showing that, under given conditions, by combination of several optical effects at different points of the sky pseudo-normal values are found, so that none of the methods of investigation was useless.

The comparison made possible by numerous parallel observations permits decision as to the accuracy and advantages of the different methods, by which—with ultimate idea of wider extension of such investigations—is to be understood reasonable cost of apparatus, ease with which it may be manipulated, and the least possible consumption of time in the observation itself and in the resulting work of calculation and tabulation. Besides these results, which somewhat pave the way for further activity in the field of atmospheric optics, others may be mentioned.

The chief argument as regards brightness, polarization, and color, and even more for their distribution over the sky is the elevation of the sun. In addition—with the sun's elevation the same—the season exerts an unexpectedly great influence. Without reference to this, entirely false conclusions are reached in the comparison of amounts relating to equal elevation of the sun. This discovery comes to astronomy probably rather opportunely at the moment when there is deliberation as to whether or not even the observed oscillations of the height of the pole find their explanation to be in part a consequence of refraction changes due to meteorological changes.

Summer is by far the most unfavorable season for observations in atmospheric optics. Only those who have made regular observations for many years on the stars in high mountain regions are in a position to appreciate the full value of the winter and the spring sky, A simple evidence is that in winter Venus is not infrequently plainly visible to the naked eye at midday, so pure and therefore so little light scattering (dark) is the winter sky. Also in California this advantage of the winter sky probably exists; Abbot has not been able, however, to avail himself of it.

The high mountain air disperses radiation very largely by molecular diffraction according to Rayleigh's law. The amounts of dispersion through diffraction, reflection, and refraction by water droplets, ice crystals, or by dust particles is to be estimated at 10 per cent for high elevations of the sun, at 30 per cent for low elevations, and it extends in the main only to about 20° solar distance with high sun, to 40° with low sun. But in the application of Rayleigh's law not only is the stratum thickness to be taken into account on approach to the horizon, but also in large measure the extinction of solar radiation on its path from the sun to the dispersing particles and from these to the observer by manifold diffusion on the multiform intervening paths, in which the extinction coefficient is not uniform as a result of change of color proceeding with dispersion of the rays, but constantly varying and always smaller for the first diffusion than for the manifold diffusion.

Position, extent in height, and composition of the disturbance strata are, as is to be expected, determinable within certain limits by the methods of observation employed, in which connection in order to prevent deception by purely local or meteorological effects it is truly more than desirable that comparisons between observations from very favorably situated stations rather distant one from another be made possible.

In the year 1912 the disturbance stratum of the atmosphere which was produced after the eruption of Katmai extended from the ground to high elevations. After the fading away of the first coarse masses, which took place in the period from June to October, 1912, it was composed of relatively coarse foreign substances generally exceeding the size of the cloud elements; with some oscillations it subsided very gradually until the second half of the year 1914. The last fading of coarser particles took place in February, 1914, at which time similar optical effects (although differently explained, it is true) were observed in the United States and at Davos. From reports available to date it is to be concluded that the fading away took place in a manner similar to that observed at Davos in the whole territory which the disturbance had embraced; that is, over the entire northern hemisphere from near the poles to the "Horse Latitudes." This argues against the existence of a brisk circulation exchange in the atmosphere over those latitudes; and there is indication in exactly that direction by some optical phenomena, which are most easily explained by the greater tenuity of the atmosphere in the warm season, for example the yearly march in different spectral portions of solar radiation, increasing with decreasing wave length and manifesting itself very significantly in the ultra-violet in marked excess of the autumn value over the spring value in the intensity and extent of the same.

During the solar disturbances occurring fitfully in 1915 and in the first half of 1916, accompanied by entirely characteristic phenomena, very readily observed in the "telluric solar corona," and quickly fading, and also during those in the second half of 1916, and at the beginning of 1917, occurring intensely and continuously and then gradually subsiding during 1917 and 1918, the disturbance stratum never reached the earth, but floated at varying height and always at great elevation, and was of massive thickness, consisting of particles of the minuest mass, estimated at 0.75 μ and from 10 to 40 times as large, the maxima not exceeding the size of the cloud elements.

How the proofs of these explanations were produced must be gotten by reference to the original paper. The change in absolute brightness of the different components manifests itself most abundantly, although it is certainly most difficult to be observed and requires simultaneous measurement of polarization and brightness in absolute terms.

OBSERVATION OF THE PHENOMENA OF ATMOSPHERIC OPTICS.

With reference to the wider distribution of the observation of the phenomena of atmospheric optics, mention may be made as to the sequence in methods of observation that I can recommend from means at disposal and my experiences.

1. *Purely visual methods.*—Scrutiny of the sky for the "telluric solar corona" (observable only at heights above 800 meters, visible at lower elevations as Bishop's ring only at the time of coarser disturbances); maintenance of watch for colored twilight phenomena, especially the primary and secondary purple light, for which Gruner has given excellent instructions, and for the occurrence of extremely high cirri at and shortly after sunset, and for luminous clouds at night. Also in the zodiacal light the intense disturbance phenomena should be plainly noticeable, and the phenomena of meteors and auroras should occur differently in intensity, extent, and color, according as they take place in a pure or in a dust-filled atmosphere.

2. *Instrumental methods.*—The observation of the neutral points during twilight, for which Busch and Jensen have given excellent instructions in their well-known Facts and Theories of Atmospheric Polarization. These are very profitably supplemented by those of the neutral lines (the isoclinics of 45° between polarization and vertical planes) during the day and twilight. As the author has demonstrated, they make possible a very accurate decision as to the momentary degree of transmissibility of the atmosphere in all sky directions.

The observation of the diminution in brightness from the sun to the adjacent sky, which will be entered upon in detail later.

The observation of the amount of polarization at the point of maximum, and especially at the zenith during twilight.

3. *Absolute measurements of brightness.*—Of all the methods this makes the greatest demand upon the observer and requires very painstaking prosecution in determination of constants.

In my observation of the diminution of brightness from the sun to the adjacent sky, the procedure was that the sunlight was passed centrally through a fixed optical system constructed of quartz, and there were determined, photometrically and photoelectrically in numerous specrum portions extending into the ultra-violet, the radiation effects which a solar field and a sky field of a tenth of a degree diameter each released respectively. By readings of one-fourth to one-half minute, accurate to the second, in the vicinity of the sun's limb and of 1 minute at somewhat greater distance and the conversion of the time into angular distance, considering the declination of the sun, the curves of diminution of brightness could be determined rather exactly. These curves depend in greatest measure on the elevation of the sun, then on the season and on the general degree of purity of the atmosphere; for these also it is first necessary to fix normal values before it is known how to interpret the curves correctly; then they constitute an excellent criterion. In a longer paper, in the Astronomischen Nachrichten, it is shown by myself that herein lies a method for the determination of extinction, which does not depend on the momentary condition of the atmosphere. This method should be a valuable supplement to that resting only on the measurements of intensity on extraterrestrial sources of energy made at widely different zenith distances, since the latter is very unmistakably subject to the disadvantage of having to assume the atmospheric condition unchanged during a rather long time, which according to experience often proves not at all true.

From the data collected by myself I may hope that these determinations of diminution of brightness will be rather productive of results and that they will be extended to the moon as now to the sun, yes, probably to the planets. In the moonlit sky of winter I can perceive not only the "telluric moon corona," but also the isophotic formations, as in the day.

The necessity for perfection of extinction determinations for astronomy, and especially for solar investigation, will materially increase radiation measurement advances—and great advancement is indicated, thanks in no small degree to the cell method. If the astronomer is not able to determine with sufficient accuracy the amount of the permeability of the screen through which he must always look, and slight, transient changes in the same, then oscillations in the solar constant and in distribution of brightness over the sun's disk can hardly be determined with certainty. By masterly investigation Wilsing has fixed the limits within which the constancy of atmospheric condition must remain assured. An exact determination of the extinction coefficient has hardly less significance for meteorology and astrophysics.

SOLAR VARIABILITY AND TERRESTRIAL CONDITIONS.

Literature, especially American literature, lately abounds in investigations on the influence of the period of solar activity. Humphreys and Abbot called it forth by their investigations of climatic change in dependence on solar activity and volcanic eruptions; Huntington seeks to demonstrate a relation between varying distribution of spots over the sun and the air pressure distribution on the earth; according to Clayton the march of temperature in the tropics follows solar activity at an interval of three days; Nansen comes to the conclusion that the temperatures over the continents increase with the number of sun spots, while the temperatures over the oceans fall with such increase; Plaskett finds a relation between solar activity and the velocity of solar rotation; Bigelow even wishes to substitute for the monthly period the 26.68-day period of solar rotation.

There is no lack here and there of objections that the meteorological influences can mask, or be mistaken for such relations, but nowhere does there appear to be clearly expressed what is understood from our preceding discussions—increase in solar activity involves increase in extraterrestrial radiation (apparently only in the short-waved, while the long-waved appears to diminish a little), but at the same time it decreases the transmissibility of the atmosphere, differently for different wave lengths, in contrast to terrestrial disturbances with their coarser particles, which diminish all kinds of radiation approximately equally. The two factors act in opposition, and it must be known how to resolve them in order to arrive at clear results. The observation of sky brightness, polarization, and diminution in brightness from the extraterrestrial light source to the neighboring sky point the way to this. These arguments can be considered only as sidelights over the field, the limits of which are not yet evident.

A brief suggestion fraught with deep significance may close these arguments. During the solar eclipse of May 29 of this year (1919), toward whose results the eyes of the scientific world are directed in expectation of a decision as to Einstein's theory, there appeared, according to news reports, an enormous gas cloud "close to" the sun's limb. Did this cloud lie in reality neither in nor near the sun, but in the earth's atmosphere? According to observations at Davos there began in the early morning of May 29 a considerable optical disturbance, and it faded away typically and very gradually till the middle of June; from other places there are similar reports. Was the refraction change connected with such possible disturbance able to impair the value of the observation, almost reaching the limit of accuracy, for a decision as to Einstein's gravitation theory? Was any attention given to the existence of an optical atmospheric disturbance at the critical points of observation, Sobral, in Brazil and Eddington in western Africa?

SMOKE FORMATIONS IN AIR DRAINAGE.

By CLEVE HALLENBECK.

[Weather Bureau Office, Roswell, N. Mex.]

INTRODUCTION.

In a report upon the temperature and the results of orchard heating in the vicinity of Roswell, N. Mex., on the morning of April 21, 1918, Mr. Hallenbeck wrote as follows:

> There was one interesting feature of this freeze that is deserving of mention. For four or five hours the air was as nearly calm as I have ever observed for so long a period of time, and the smoke blanket was observed to drift very slowly for a short distance in one direction, then in another direction, frequently moving back over its path. Attempts to photograph heated orchards, after daylight, failed on account of the heavy smoke blanket. This condition (calm and clear) apparently was favorable to a maximum of cooling near the ground. Yet the damage to unheated orchards was mostly confined to the top halves of the trees. Mulberry trees around my residence had their tops badly frozen, while the lower foliage was unharmed. Young corn and beans, not more than 30 yards from these trees, were absolutely unharmed, although in the instrument shelter, about 200 feet away, the temperature was between 32° and 29° for four hours. Many orchardists who had not heated their orchards announced a day or two after the freeze that their crop was only slightly injured, only to discover a week later that the top halves of their trees were nearly bare of fruit.

As the lowest temperature on clear, still nights is usually at the lower elevations, we suggested to Mr. Hallenbeck that he watch the condition in the future so as to ascertain under what general conditions the high-level damage is done. The probable explanation of this interesting phenomena is apparently given in the following paper. Mr. Floyd D. Young has recorded frequent and rapid fluctuations in temperature in the citrus groves at Pomona, Calif., due generally, however, to mixing of the warmer upper air with the cold-surface air. These fluctuations are most marked above the tops of the groves and when there is a strong air draft at the 30-foot level. In one instance recorded, there was a change in temperature of 10° in four minutes at an elevation of 15 feet. At the 5-foot level at the same time there was very little interruption in the steady fall in temperature.—*J. Warren Smith.*

SMOKE FORMATIONS IN AIR DRAINAGE.

The figure here shown was constructed from sketches made on the morning of December 9, 1919. Each of the seven parts of the figure is a duplicate of the others, except for the smoke formations. In the foreground is a screen of orchards and shade trees; in the distance the visible horizon is indicated by a single line. At the extreme right the ground rises into what is known as "North Hill," on which the smokestack of the Military Institute is shown. At the extreme left is "vapor" rising from a flowing irrigation ditch. All the smokestacks are in a general north and south line, except the one at the left, which is about 0.3 mile farther west, while the irrigation ditch was within 100 yards of the observer. The smoke formations were observed and sketched from a point about 1 mile east of the city, the horizontal distance included being, at the line of smokestacks, about 1.6 miles. The general slope of the ground is ESE, but this slope is not visually perceptible east of the city.

It was, of course, impossible to go into detail in making a quick sketch of eight or nine different smoke clouds that were constantly changing, but the formations as shown are sufficiently accurate in general outline. Figure A was drawn from memory.